NRL Memorandum Report 1817

Information on Over-the-Horizon Radar

Part XIV - HF Radar Performance at More Than One Hop

[Unclassified Title]

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CONTENTS

ABSTRACT

Operational records of detections of aircraft and missiles at more than one-hop distances are disclosed. It has been found that these detections are not significantly different from one-hop detections although the modes are inherently less dependable.

PROBLEM STATUS

This is an interim report on a phase of the problem; work is continuing.

AUTHORIZATION

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INFORMATION ON OVER-THE-HORIZON
RADAR - PART XIV - HF RADAR PERFORMANCE
AT MORE THAN ONE HOP
(Unclassified Title)

INTRODUCTION

During the past several years of operation of the NRL OTH radar, the detection of targets via OTH propagation paths has become unremarkable through repetition. It is of interest now to consider extending the technique into regions of multiple hop propagation. To this end let it be noted that for a non-zero vertical width of beam and for targets at unverified locations there is some uncertainty in mode extraction from specific OTH data.

This report describes some alleviating circumstances to permit mode adjudication and chronicles portions of the NRL operating experience supporting the possibility of multi-hop serveillance.

MODE SELECTION

A ground distance of 2000 nmi can be used as the nominal boundary where 1F illumination terminates and a 2F mode must be used. The actual boundary is variable over several hundred miles being a function of frequency, height of maximum ionization, and any horizontal ionization gradients. For targets at distances between 1500 and 2200 NMI, the illumination mode is uncertain when a continuum of earth backscatter exists from short to long distances. The mode uncertainty can be relieved if vertical plane angle of arrival is measured or if the target's track is known.

The sketch, Fig. 1, illustrates the modes referred to herein. Many of the NRL aircraft observations have been concentrated at distances where 1F- and/or 1F+ was the most likely mode, but there have been some exceptions. Missile launches have been observed via all modes shown, as follows: launches from AFETR Cape Kennedy at 600+ nmi via 1F- and an occasional 1F+, from the Atlantic at about 2200 nmi via 1F+ and 2F-, from Green River at about 1600 nmi via 1F+ and 2F-, and from AFWTR at 2150 to 2600 nmi via 1F+, 2F-, or 2F+ path. Typically more than one mode will be effective during a single event but not necessarily in simultaneity.

AIRCRAFT OBSERVATIONS

The detection of aircraft by two hops has been given little specific attention, although on occasion it has been obvious that the target distance was too great for a single ionospheric refraction. At any one time, MADRE observations have generally been confined to a single 450 nmi interval with

1350 to 1800 nmi slant range being the most distant one in heavy use. The raw operating notes made while aircraft watching during years 1962-1964 have been examined, and it was found that in all instances where the range interval 1800-2250 nmi was scrutinized at least one aircraft was detected at a slant range of more than 2000 nmi. Table I gives dates and tracking end points (slant range) in nautical miles; the length of the track does not have any real significance since a target may have been watched just long enough to make sure it was an aircraft, or it may have been kept under surveillance as long as possible without any radar adjustment, or in a few cases every effort was made to continue the tracking. For the tracks the PGGT σ product ran between 130 and 140 db (estimate). These targets were not necessarily seen via a two hop mode, but it is likely that most of them were. About the only inference that should be drawn is that whenever the operators happened to examine ranges beyond 2000 nmi some aircraft targets were seen (and no doubt these more distant intervals were tried only when propagation conditions were appropriate). The only track out of this set that has been subjected to a real mode analysis is the one of 11-29-62; this was a P3 flight made for NRL. The track was described in NRL Report No. 6272 (SECRET), but no mode description was made therein. Sometime after the Report publication, a study was made of the flight using the navigators log, radar range and speed measurements, and ionospheric data. The study provided a good mode assessment: the track was by 2F for slant ranges 2072 to 1630 nmi and by 1F from 1610 to 1466 nmi. A general quality statement can be made for all cases of aircraft detected by two hop or suspected two hop modes: there were no obvious distinguishing features other than lower amplitude signals; that is, any degradation in doppler frequency integrity was small with reference to an analysis bandwidth of 1/3 cps.

Missile launch detections have been accomplished by way of 1F-, 1F+, 2F-, and 2F+ illumination geometries. One such detection was achieved 2-28-62 on an AFWTR Atlas, Test 355201, and was reported upon in NRL Report No. 5811 (SECRET). It is appropriate to briefly review this test since radar operation was planned for a two ionospheric refraction illumination. Figures 2 and 3 show the range distribution of the earth echo, and illumination was obviously by two hops. Figure 4 is a line sketch showing the geometry; while operating in the missile detection mode alternate 450 nmi range segments were processed beginning at 450 nmi. Figure 5 is a running time sequence of doppler frequency versus range readouts. In the frame for T_0+39 sec a spread doppler signal is evident from 35 cps to 45 cps at a range of 230 nmi as read from the bottom of the scale. This corresponds to a detection slant range of

$$2250 + 230 = 2480 \text{ nmi.}$$

The diffuse doppler signal (characteristic of thrusting missiles with the form of display used) is apparent again in the time frames beginning with 1 min 15 sec and ending with the picture labeled 2 min 7 sec. The Atlas was no higher than 20 km at first detection, and although the signals were weak, the antenna gain was probably about 10 db less than was used for the aircraft detections described.

The earth echo distribution in range has not always so clearly indicated the modes as in the example just described. Several later missile detections will be treated in a summary form. To determine the adequacy of multiple hop propagation for the detection of ballistic missile launches, two sets of OTH radar data were submitted to computer analysis: the first being radar signatures obtained in viewing AFWTR tests during 1963; the second, the radar results for Athena launches from Utah during the summer and fall of 1965. Digital machine computation is based on post-flight trajectory information for each vehicle or a nominal of its type and the best obtainable estimate of the appropriate ionospheric layer height. The AFWTR test results are given in Table II. Test number, missile type, date and lift-off time are listed. In each of these tests except two, the 0911 and the 1792, discernible missile signatures were obtained. A tabulation, not shown, was made of the slant range at which signals were detected versus time after launch. These experimentally determined slant ranges were compared with the computer analysis for the permitted modes, times, and slant ranges. In the table, a coincidence between the radar signal time and range and the computed time and range is shown as an X under the appropriate mode. Thus multiple mode entries indicate detection for some particular time of powered flight, without implication that detections were simultaneous, although coincidence is not prohibited per se. There are points along most trajectories where two modes exhibit the same slant range and in such events discrimination is possible using doppler and doppler rate information; however this refinement was not employed. Only one test, the 0210, evidenced detection by a 1F- mode; all of the others required a more complex propagation including one or more ground reflections with intervening ionosphere refractions. The detection ranges (slant) for the above table had values from 2180 to 2640 nmi.

Results on the basis of slant range comparisons are not available for the Athena launches. Constant acceleration filtering has been applied to several tests observed during the summer and fall of 1965. Various propagation modes have been tested to achieve an agreement between the observed doppler time history and the trajectory data. In eight of the thirteen tests studied, agreement was evident for 1F+ and 2F- modes; the 1F- mode's failure to show might have been due to its acceleration being too small for the filters used. The detection slant ranges for the Athena launches varied from 1580 to 1640 nmi.

The earth echo has been studied as received after two ionospheric refractions. Some of the work done at NRL is described in Proceedings of the ARPA Meeting 1965 and 1966. The earth target is considered to provide a good index for performance assessment and some statements can be made:

(a) When examined with one-tenth cps resolution filters the doppler extent of a two-hop "highlight" is not much different from that of one hop, but the lifetimes are longer for one hop.

(b) There are times when good two-hop illumination cannot be achieved for very modest ranges - just beyond the one-hop coverage; two-hop performance is inherently less reliable than one hop.

CONCLUSIONS

Perusal of aircraft tracking records for the interval 1962 to 1964 reveals many observations beyond 2000 nmi, the nominal range limit for one-hop detection. No record was uncovered of any unsuccessful attempt to detect at these extreme ranges, strongly suggesting that a knowledgeable operator can recognize conditions conducive to success in this endeavor. For one track of an aircraft on a verified path, careful analysis confirmed multiple hop propagation.

Modes for missile launch detections are thought to be more readily determinate than for aircraft because of the higher speeds and altitudes and the non-horizontal travel. At ranges between 1600 and 2600 nmi, in the examples included herein as well as many others, detections by paths of more than one refraction have been conclusively established.

Two-hop performance is inherently less reliable than one hop, but is not significantly different in character. Even when successfully employed it cannot always remove coverage gaps in the skip zone beyond the first earth reflection.

Date	Terminals for Tracks Extending beyond 2000 nmi	
	Start	End
8-23-62	2064	2243
9-2-62	3254	3263
10-17-62	2035	1829
11-29-62	2072	1466
3-28-63	2217	1467
11-7-63	2084	2159
9-24-63	2372	2281
	2339	2372
	2303	2340
	2302	2329
	2341	2281
3-5-64	2064	2006
	2188	2193
2-13-64	2551	2478
	2439	2402
	1902	2017
2-7-64	2077	2090
	1963	2075

TABLE I

Test	Vehicle	Date	Time Hr:Min:Sec EST Time	Effective Mode				
				1F-	1F+	2F-	2F+	3F- etc.
0210	Titan I	1-29-63	18:31:45	x	x	x		
0216	MinMan	4-11-63	15:30:49			x		
0410	Atlas E	4-24-63	15:59:38		x	x	x	
0911	MinMan	4-30-63	13:46:07					
0968	MinMan	4-13-63	15:41:51				x	
1335	Atlas E	7-3-63	16:13:57			x	x	
1365	Atlas E	7-26-63	14:18:32					x
1536	Titan I	8-30-63	14:27:18		x	x	x	
1618	Atlas E	7-30-63	12:36:50			x		x
1651	Atlas D	7-31-63	15:52:51			x		x
1792	Titan II	9-23-63	10:26:03					
1836	Atlas D	9-11-63	15:59:56		x	x	x	x
1938	Titan I	9-17-63	15:15:13		x	x	x	x
2313	MinMan	10-31-63	16:13:39				x	x
2539	MinMan	12-13-63	16:24:16		x		x	x
2673	MinMan	11-27-63	10:53:32			x		x

TABLE II

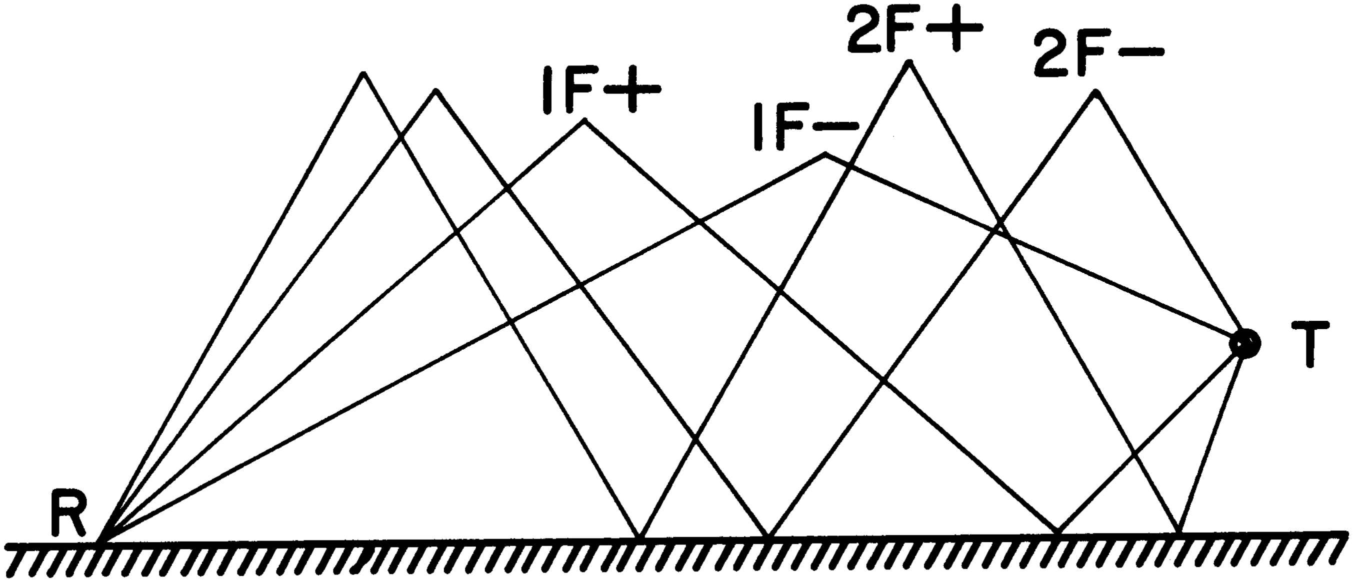

Figure 1

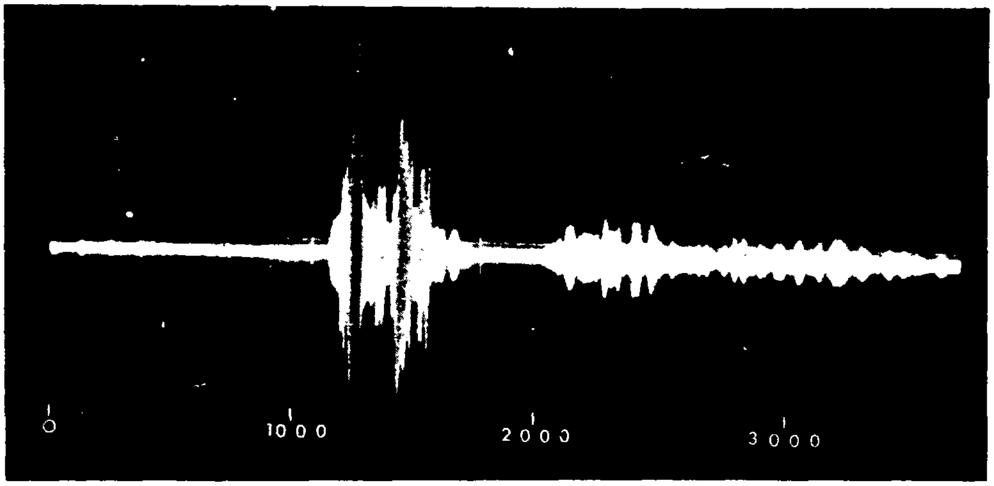

Fig. 2 – Backscatter amplitude at a 500 kc I-F on the vertical versus slant range in nautical miles on the horizontal. Time of picture is about thirty minutes prior to launch.

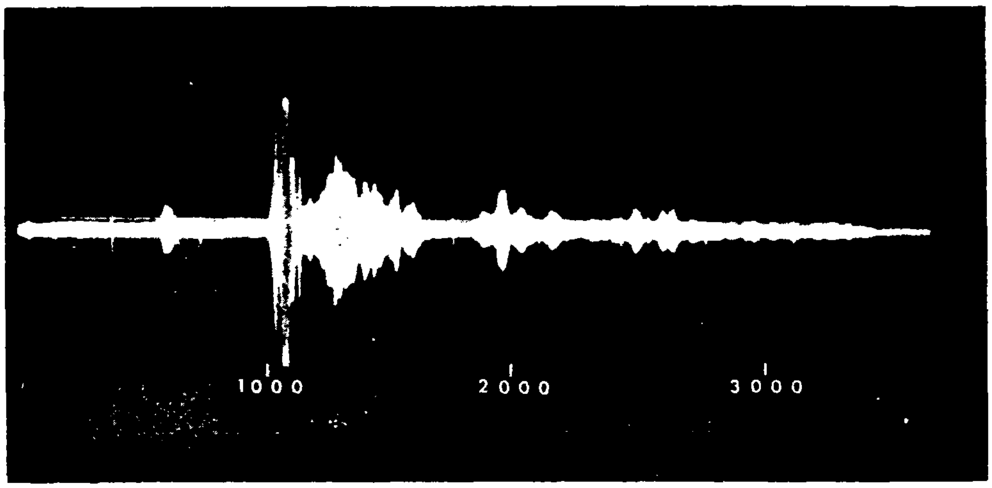

Fig. 3 – Backscatter amplitude at a 500 kc I-F on the vertical versus slant range in nautical miles on the horizontal. This picture was taken five minutes after launch.

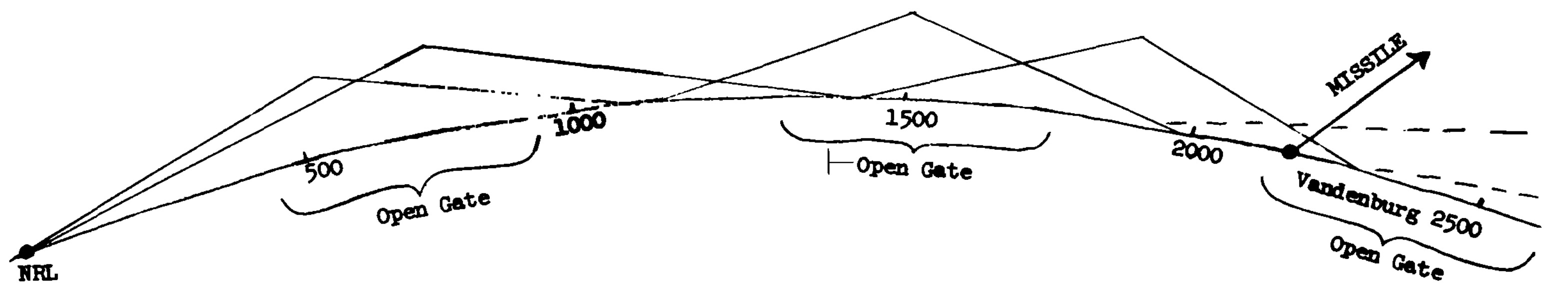

Fig. 4 - A sketch of the limiting paths by which 2nd hop backscatter of high level was received. Range is given in nautical miles.

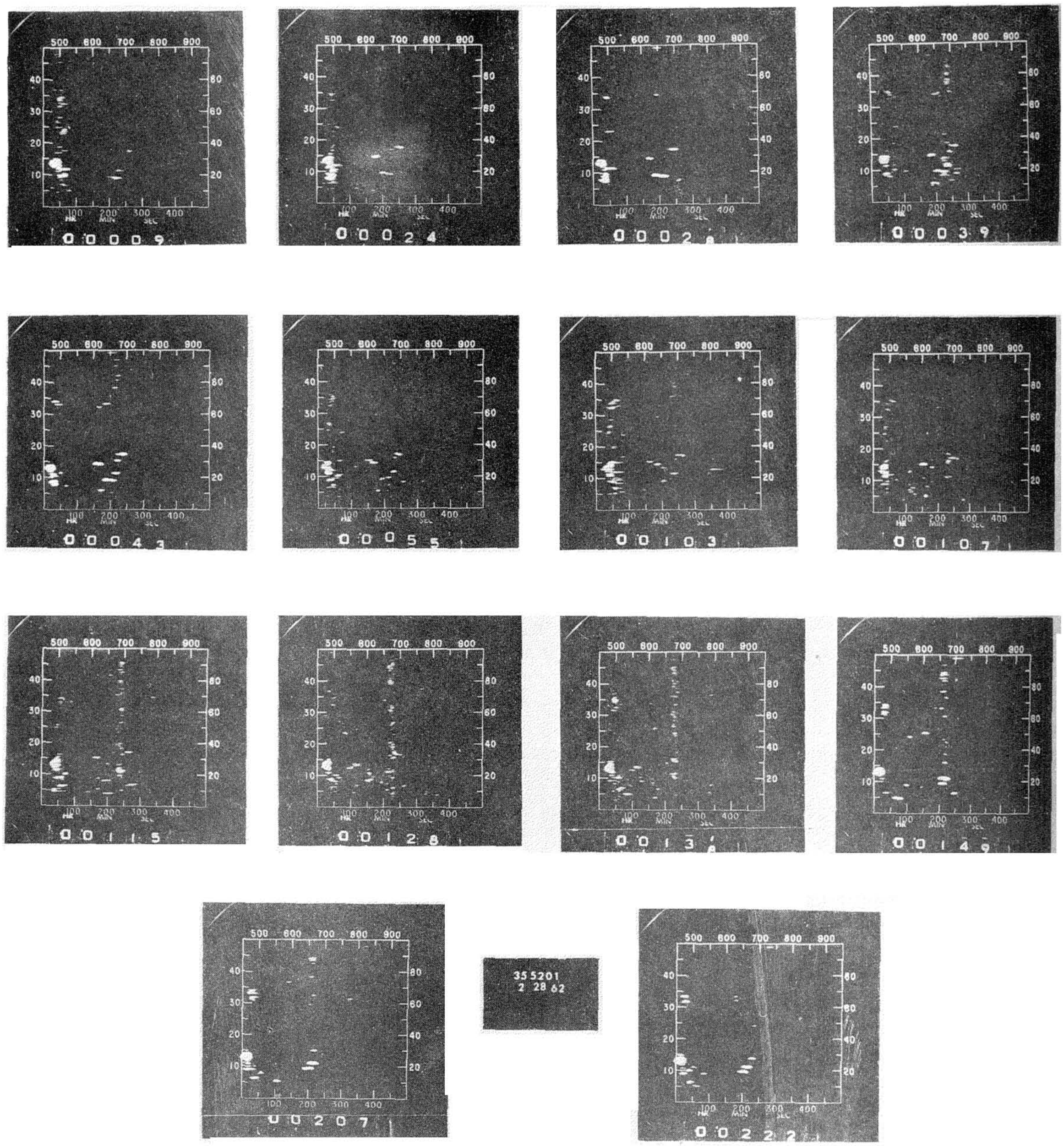

Fig. 5 – Pictures of the Madre display taken after missile launch. Times are given in the form of hours, minutes, and seconds. The vertical ordinate has 45 cps available for target doppler. The horizontal ordinate gives a 450 naut. mi. range interval.

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13. ABSTRACT

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(PAGE 2)